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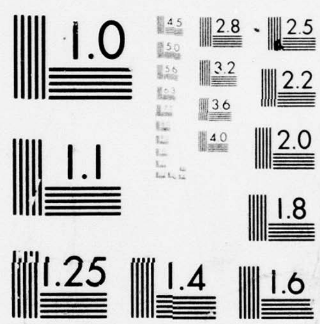

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The Role of Lubricant Type and Substrate Composition in Thermally Induced Oil Migration

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6 December 1977

Interim Report

Prepared for
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Los Angeles Air Force Station
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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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The dependence of thermally induced oil migration on substrate composition and lubricant type has been investigated. It was found that, unless dewetting occurs, the substrate composition does not affect the rate of migration. It was also verified that oils other than Apiezon C undergo thermally induced oil migration. These results agree with the predictions of our theoretical model. Finally, the relative stability of grease films to temperature gradients of the same magnitude was demonstrated.

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I. INTRODUCTION

Liquid lubricants are used in most spacecraft moving mechanical assemblies (MMA) in the form of thin oil films 2 to 5 μm in thickness. For extended missions (> 5 years), oil reservoirs (impregnated porous materials) are inserted into the MMA bearing annulus to facilitate the replenishment of lubricant lost by evaporation. In order to sustain acceptable performance throughout the operational lifetime of the MMA, it is desirable to maintain film thickness levels and oil distribution such that flooding or lubricant starvation cannot occur within a bearing cavity. Limited information exists, however, on the vapor transport and surface migration characteristics of lubricant oils impregnated into retainers and reservoirs or residing on the internal surfaces of an MMA bearing cavity. This lack of lubricant transfer data makes it impossible to model a priori the lubricant distribution within an MMA as a function of time and operating parameters.

This is one of a series of reports in which experiments that deal with these questions are described. In earlier reports,[1-7] the mechanics of thin oil film migration under the influence of a temperature gradient was explored, and the efficacy of porous lubricant reservoirs was discussed. We now examine the role of lubricant type and substrate composition in thermally induced oil migration. The experimental observations agree with the theoretical predictions of our model.

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II. EXPERIMENTAL TECHNIQUE

The experimental apparatus was the same as that used in earlier studies.[3-7] The distribution of oil films on metal substrates was determined through photography of their fluorescence under ultraviolet light. The oil films were prepared by both dip coating and swabbing. The only new procedure developed for this study involved the preparation of thin grease films, where small quantities of the appropriate grease were squeezed between the metal substrate and a glass slide. When the glass slide was slid off the substrate, a thin grease film was left behind.

The studies reported on in this paper were all conducted in air. Previous work had not demonstrated any noticable dependence of oil migration upon the presence or absence of vacuum.[5]

The average temperatures of the substrates were not controlled in this work. Instead, the substrates were left free to reach whatever average temperature was necessary for the attainment of the desired temperature gradient. This resulted in an average temperature of the substrates of 5° to 10°C above room temperature, depending upon the magnitude of dT/dx.

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III. REVIEW OF THEORY

Because of the temperature variation of the surface tension γ, the imposition of a temperature gradient dT/dx on a thin liquid film produces a driving force per unit area τ at the liquid vapor interface. This driving force is given by

$$\tau = \frac{d\gamma}{dx} = \frac{d\gamma}{dT}\frac{dT}{dx} \qquad (1)$$

At the solid-liquid interface, on the other hand, the zero slip condition is assumed, i.e., the condition that no liquid motion occurs there.

The above assumptions are the basis for the prediction of a velocity profile in the liquid film as shown in Fig. 1. The average flow velocity of such a film of uniform thickness h and viscosity η is given in Ref. 3.

$$v = \frac{h\tau}{2\eta} \qquad (2)$$

Fig. 1. Velocity Profile of a Thin Oil Film of Uniform Thickness h

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IV. RESULTS AND ANALYSES

A. ROLE OF SUBSTRATE COMPOSITION

In discussing the role of substrate composition, we must distinguish between the occurrence of dewetting and oil migration without dewetting. Thermally induced oil migration occurs when oil that has the higher surface tension (at the colder end of the substrate) pulls the remainder of the oil toward itself. If dewetting occurs, whereby the oil film breaks up into disconnected drops, thermally induced oil migration is not possible. Therefore, because it affects the wetting ability of the oil, the substrate composition is an important parameter.

If, on the other hand, dewetting does not occur, and the oil film remains continuous, the substrate composition may still affect the rate of migration. There are at least two possible mechanisms for this to occur. First, our model assumes that the solid-liquid interface does not contribute to the driving force because the condition of zero slip is accepted as correct. In fact, the condition of zero slip causes some difficulties in the development of theories of fluid motion[8] and may require modification. This would mean that this type of oil migration would be substrate dependent because the degree of slippage would be. Second, our model assumes that the viscosity of the thin film is identical to that of the bulk fluid. However, there is some evidence that the presence of a solid surface can result in long-range order in liquids such that the viscosity becomes anomalously large.[9] An anomalous viscosity would produce a velocity profile as shown in Fig. 2, and substrate composition could again be important.

The dependence of the rate of oil migration on substrate composition was investigated by observing oil films on 347 steel, 440-C steel, 17-4 PH steel, and Ti-6Al-4V substrates. No significant differences were noted in the rates of oil migration on these materials. However, a better check

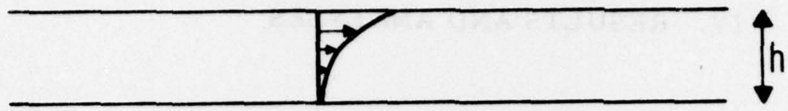

Fig. 2. Velocity Profile of a Thin Oil Film with a Substrate-Induced Anamolous Viscosity

would involve the use of a surface radically different from those studied to now. Toward this end, one of our substrates was coated with a commercial Teflon-like substance (Crown 6069 Permanent TFE Coating) according to manufacturer's directions. The TFE is a low-surface-energy material in contrast to the high-surface-energy metals previously investigated. The TFE substrate was cleaned successively with soap, de-ionized water, and heptane. An oil film of Apiezon C was then swabbed on as described earlier,[7] and a temperature gradient of 2°C/cm was imposed.

The resulting oil distribution after one day is sketched in Fig. 3. Rapid oil migration has occurred on the TFE surface much like that observed on the metal substrates. Thus, there does not appear to be any radical dependence of thermally induced oil migration on substrate composition as long as dewetting is absent.

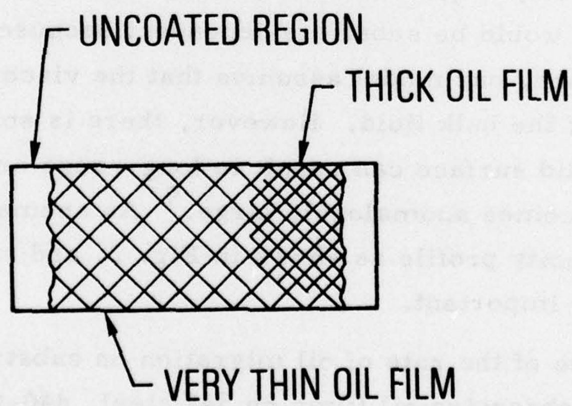

Fig. 3. Oil Distribution on TFE-Coated Substrate After One Day with $dT/dx = 2°C/cm$. The colder side is on the right.

B. ROLE OF LUBRICANT TYPE

1. BASE OILS

Our studies to now have dealt exclusively with Apiezon C, a paraffinic mineral oil. One question concerns whether or not the same type of migration behavior can be expected from other oils, including the recently developed synthetic oils. For an answer to this question, we first examine the theoretical expression for the flow velocity Eq. (2). Here, the lubricant properties enter through both the viscosity and the temperature derivative of the surface tension. The equation predicts that higher viscosity oils should migrate more slowly, but otherwise the migration should proceed in the same manner as for Apiezon C. For the factor involving the surface tension, we make use of the experimental fact that the surface tension of most liquids decreases linearly with temperature, approaching zero at the critical temperature. An empirical relationship for this is[10]

$$\gamma = \frac{K}{V^{2/3}} (T_c - T) \tag{3}$$

where V is the molar volume and K = 2.1 ergs/°C. This yields

$$\frac{d\gamma}{dT} = - \frac{K}{V^{2/3}} \tag{4}$$

Equation (4) indicates that $d\gamma/dT$ is always negative and is approximately the same for equivalent-sized molecules. Therefore, the most we would expect, on the basis of this analysis, is that different oils might migrate at different velocities than Apiezon C.

For verification, we investigated three other oils in addition to Apiezon C: KG-80, a paraffinic mineral oil; Krytox 143AC, a perfluoroalkylpolyether; and Brayco Micronic NPT 4-I.G., a synthetic, ester base lubricating oil. We found that all of these oils migrated in the same manner as Apiezon C, in agreement with the preceding analysis.

2. ADDITIVES

Pb napthanate is an additive commonly used in Apiezon C. One important question concerns whether or not its presence affects the migration properties of the base oil. We first note that Pb napthanate, when present in the oil, is not found in the liquid-vapor interface. This has been established through investigations of the oil by use of ESCA (electron spectroscopy for chemical analysis), an analytical tool used to determine the chemical composition of surfaces. The application of ESCA to the additive containing oil reveals no trace of the additive. The absence of the additive from the liquid-vapor interface is also implied by the fact that Pb napthanate does not change the surface tension of the base oil by its presence in the bulk.

Since the additive avoids the liquid-vapor interface, it cannot have any effect on the driving force as given by Eq. (1). Therefore, in the absence of dewetting, we expect that the migration characteristics of Apiezon C would not be strongly influenced by the additive. We have verified that such is indeed the case.

On the question of dewetting, ESCA studies have also revealed that the additive is preferentially adsorbed at the solid-liquid interface and therefore might be expected to affect the wetting characteristics of the oil. Our observations of the migration of the oil both with and without the additive have indicated, however, that the tendency to dewet is approximately the same for both. In addition to these observations, we conducted the experiment described below.

Three samples were prepared by using clean, polished 347 steel substrates. For sample 1, a 10 μl drop of Apiezon C was placed on a substrate; for sample 2, a 10 μl drop of Apiezon C with 2% Pb napthanate was placed on a substrate; for sample 3, a 10 μl drop of Apiezon C was placed on a substrate that contained a film of Pb napthanate. The film was produced by dipping the clean substrate first in a solution of 10% Pb napthanate in heptane

for 5 min and then in pure heptane for 5 min. It was verified by ESCA that a film of the additive is produced by this process.*

The spreading behavior of the drops in the three cases was then compared. All three drops spread at approximately the same rate which indicates that the additive does not strongly modify the wetting characteristics of the oil.

3. GREASES

Greases are compound fluids that consist of a base oil plus a thickening agent. Our interest concerns the behavior of thin grease films under the influence of a temperature gradient.

A temperature gradient might affect a grease film in one of two ways. First, it could induce a migration of the entire film in much the same manner as for oil films. If this were to happen, however, it would occur at a greatly diminished rate, because Eq. (2) predicts the flow velocity to be proportional to the inverse of the viscosity. Second, it could induce a migration of the oil alone, which would cause the oil to separate from the thickener.

For our investigation of the effect of a temperature gradient, we prepared thin films of the following greases: Brayco Micronic 803, Krytox 143 AZ, Krytox 143AB, Andok C, and KG-80. These films were subjected to a temperature gradient of approximately 1°C/cm for 8 weeks and then to a gradient of 2.6°C/cm for 9 weeks. There was no indication of migration or separation noted in any of the five greases. Thus, thin films of these greases appear to be considerably more stable than oils in the presence of a temperature gradient.

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*R. W. Phillips and L. V. Tolentino (to be published).

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REFERENCES

1. L. M. Dormant and S. Feuerstein, Nylasint Pore System: Reservoir or Sink, TR-0076(6270-30)-2, The Aerospace Corporation, El Segundo, Calif. (29 July 1975).

2. L. M. Dormant and S. Feuerstein, Lubricant Reservoir System: Thermal Considerations, TR-0076(6270-30)-1, The Aerospace Corporation, El Segundo, Calif. (9 October 1975).

3. A. A. Fote, L. M. Dormant, and S. Feuerstein, Migration of Apiezon C on Metal Substrates Under the Influence of Temperature Gradients, TR-0076(6892)-1, The Aerospace Corporation, El Segundo, Calif. (15 October 1975).

4. A. A. Fote, Migration of Apiezon C on Metal Substrates Under the Influence of Temperature Gradients: Mathematical Model, TR-0076(6270-30)-4, The Aerospace Corporation, El Segundo, Calif. (30 December 1975).

5. R. A. Slade, A. A. Fote, and S. Feuerstein, Thermally Induced Migration of Apiezon C. The Effects of Vacuum and Surface Finish, TR-0076(6270-30)-6, The Aerospace Corporation, El Segundo, Calif. (17 March 1976).

6. A. A. Fote, R. A. Slade, and S. Feuerstein, Surface Transport of Oil in the Presence of Nylasint and Microwell Reservoirs, TR-0076(6270-30)-7, The Aerospace Corporation, El Segundo, Calif. (19 July 1976).

7. A. A. Fote, R. A. Slade, and S. Feuerstein, Barriers to the Surface Transport of Oil, TR-0077(2270-30)-3, The Aerospace Corporation, El Segundo, Calif. (18 February 1977).

8. C. Hugh and L. E. Scriven, "Hydrodynamic Model of Steady Movement of a Solid/Liquid/Fluid Contact Line," J. Colloid. Interface Sci. 35, 85 (1971).

9. A. W. Adamson, Physical Chemistry of Surfaces, Interscience Publishers, New York (1967) p. 322.

10. A. W. Adamson, Physical Chemistry of Surfaces, Interscience Publishers, New York (1967) p. 55.

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